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The role of bacterial fertilizers in the formation of legume crops

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Abstract. The article presents the results of studies of the effect of bacterial fertilizers on the yield formation of grain legumes (soybean and lentil). The effect of root fertilization with Azotovite and Phosphatovite, fertilizers containing live cells and bacterial spores, on the structure of yield and yield capacity of legumes, the quality indicators of soybean and lentil grains were studied. The results obtained indicate that fertilizing with bacterial fertilizer Phosphatovite accelerates the maturation of legumes and increases the safety of plants for harvesting. Fertilizing plants with Azotovite and Phosphatovite contributed to an increase in soil microbiological activity. Bacterial fertilizers make it possible to obtain more seeds from soybean and lentil plants, while the content of crude protein, fat, and nitrogen in the grain increases. On average, over the years of research, fertilizing with bacterial fertilizers significantly increases the yield of legumes. It is noted that the efficiency of Azotovite is lower in conditions of insufficient precipitation during its use. In the conditions of the Chuvash Republic in legumes, fertilizing with Phosphatovite increases the productivity of plants.

1 Introduction

In the conditions of agricultural production intensification, special attention is paid to ensuring a stable increase in crop yields. One of the factors of increasing the productivity of plants is providing them with nutrients, but the use of mineral fertilizers does not allow to obtain environmentally friendly products. Bacterial and microbiological preparations serve as an alternative to chemical fertilizers. Biologization of agriculture contributes to the maintenance of soil fertility and environmental safety [1, 2]. Bacterial preparations, being an element of biological agriculture, are now increasingly used in the cultivation of agricultural crops [3, 4, 5].

Legumes are a valuable source of vegetable protein, they also have the ability to enrich the soil with nitrogen, which makes these crops irreplaceable in cropping system. In recent years, the acreage under these crops has been increasing, nevertheless, their productivity remains low. Its increase is facilitated by the use of fertilizers [6]. Bacterial and microbiological fertilizers increase the yield and grain quality of legumes [7, 8, 9], enhance

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their symbiotic activity [10, 11]. Studies have established the effectiveness of the use of various microorganisms to enhance the activity of nitrogen-fixing bacteria [12, 13].

A number of researchers point to the effectiveness of the use of microbiological fertilizers in soybean and lentil cultivation for seed inoculation and as top dressing [14-18].

2 Materials and Methods

In the experiments, bacterial fertilizers Azotovite and Phosphatovite were studied, which were used as root fertilizing in the cultivation of grain legumes (soybean and lentil). The preparaion Azotovite, containing live cells and spores of the bacteria Azotobakter chroococcum, increases nitrogen-fixing properties. Phosphatovite contains living cells and spores of Bacillus mucilaginosus bacteria, which convert insoluble phosphorus and potassium compounds into a form accessible to plants. The studies were conducted in the northern zone of the Chuvash Republic in 2019-2020 on light gray forest soil of medium loamy granulometric composition. The soils of the experimental site were characterized by a low humus content – 2.67%, increased P_2O_5 19.3 mg/100 g, average K_2O – 17.2 mg/100 g of soil, pH – 5.4.

Legumes were used as objects of research: soybeans of the northern ecotype of the SibNIIK 315 variety and large-seeded lentil of the Vekhovskaya variety.

The experiment options were as follows:

- control,
- fertilizing with Azotovite,
- fertilizing with Phosphatovite,
- joint fertilizing with Azotovite and Phosphatovite.

The plot area was 3.6 m^2, the repetition in the experiment was sixfold, the placement of plots was randomized. The sowing of legumes was carried out in the middle of the second decade of May. Soybeans were sown in a raw (15 cm) with a seeding rate of 0.6 million germinating seeds/ha, lentil - also in a raw (15 cm) with a seeding rate of 2.0 million germinating seeds/ha. In the budding phase, the first root dressing with bacterial preparations was applied, and the second - ten days later. The consumption of preparations is as follows: 30 ml of the preparation per 10 liters of water, with a consumption rate of 5 liters/m^2. Phenological observations, accounting of plant density, linear growth dynamics, yield structure were carried out according to the methodology of the State Variety Testing. The structure of the legume crops was determined on 30 plants of each repetition, the harvest was recorded using a continuous method. The biological activity of the soil was determined by the method of flax linen decomposition. Qualitative analysis of seeds was determined by the methods: crude protein (GOST 32044.1-2012); crude fat (GOST 13496.15-2016); fiber (GOST 31675-2012); nitrogen (32044.1-2012); phosphorus (GOST R 51420-99). Mathematical processing of experimental data was carried out according to the method of B.A. Dospekhov.

3 Results and Discussion

Studies conducted over two years have shown the effectiveness of root fertilizing with bacterial fertilizers Azotovite and Phosphatovite.

The years of research differed in weather conditions, the effect of preparations on crops was also different. 2019 was characterized by moderate temperature and excessive moisture supply, especially at the end of the growing season. The first months of the growing season were quite warm, exceeded the long-term temperature data by 2^0C higher. May was quite warm, the average monthly temperature was above 3.8°C, in June the average monthly temperature was in the range of long-term data. The second half of the growing season turned out to be less favorable in terms of air temperature: in July it was 1.6°C colder. There was little precipitation at the beginning of the growing season, and the end of June - the beginning of July they were characterized by heavy precipitation, which exceeded the long-term average almost by 2 times, in July precipitation fell by 25% more. In general, the growing season of 2019 differed little in temperature conditions from the average long-term observations, but it was characterized by an abundance of precipitation in the middle of the growing season, the hydrothermal coefficient was 1.31. The growing season of 2020, it turned out to be somewhat warmer and was distinguished by an abundance of precipitation in the middle of the growing season, which affected the growth and development of leguminous crops. Unfavorable conditions for plant growth were observed in May. Low temperature and heavy precipitation did not allow to start sowing on time, which in general affected the lentil yield, for soybean, the sowing time turned out to be optimal. In terms of the amount of heat, July differed from the average long-term observations, when the average monthly temperature was 2.2°C higher, and August practically did not differ in temperature from the average values. Excessive precipitation was observed in July. In general, the growing season of 2020 differed slightly in heat, but turned out to be wetter compared to long-term observations, the hydrothermal coefficient was 1.62.

The duration of vegetation in 2019 was 124-128 days for soybean, 118-122 days - for lentil with the highest value in the control, in 2020 it was shorter: 106-110 days for soybean, 83-90 days - for lentil. The use of Phosphatovite fertilization accelerated the maturation of legume seeds by an average of 4-5 days compared to the control and the variant with Azotovite fertilization.

The field germination of soybean was 73.3-74.5% in 2019, 79.2-80.5% – in 2020, there were practically no differences in the variants, since bacterial fertilizers could affect only the safety of plants. The safety of soybean plants for harvesting turned out to be quite high: in 2019, 90.6-99.0%, in 2020, 95.8-100%. In the variants with top dressing, it turned out to be 4.2-8.5% higher than in the control.

In 2019, the field germination of lentils was in the range of 74.0-78.5%, the safety of plants for harvesting was quite high and amounted to 92.7% in the control, 94.2-94.6% - in experimental variants. In 2020, field germination was 62.5-64.0%, the safety of lentil plants for harvesting was 89.6%-92.9%, which is lower than in the previous year by 1.4-3.1%. The indicators were somewhat better preserved in the variants where bacterial fertilization was used.

Fertilizing with bacterial fertilizers had an impact on the biometric indicators of soybean and lentil plants. In experiments with soybean in 2019, the tallest plants were obtained in the variant with Nitrogen and Phosphatovite fertilization – 67.5 cm, which turned out to be 8.6 cm higher than the control, the shortest plants were in the control variant. The first bean was formed at a height of 10.4-11.9 cm, and in terms of the number of branches, the variants differed little from each other (1.5-1.9 pcs.). In 2020, fertilizing with Azotovite led to a more intensive growth of vegetative mass, the height of plants in the variant was 85.3 cm, which turned out to be higher than in the control by 6.3 cm, the number of leaves increased by 2 pcs., the plant weight by 12.8 g. When fertilizing with Phosphatovite, the plants turned out to be shorter than in other variants, but number of leaves and the plant weight were higher than in the control and the variant with Azotovite.

In 2019, lentil plants turned out to be taller. In the budding phase, their height averaged 32.0-32.8 cm, and in the maturation phase it increased almost 2 times up to 58.7-64.9 cm. The use of Azotovite increased the height of plants by 5.4-6.2 cm compared to the control, Phosphatovite did not have such a significant effect. In the same variants above, the first productive bean was formed. Nevertheless, there were slightly fewer branches in the variants where Azotovite was used, their number increased when fertilizing with

Phosphatovite only. In 2020, there were no significant differences between the variants in terms of biometric indicators of plants, plants in the variant with Phosphatovite fertilization were slightly lower – 33.3 cm, which was 2.2 cm lower than the control. According to the height of the first lower bean formation, there were no differences between the variants, the first productive bean was formed at a height of 20.9 to 22.3 cm. More branches were formed on plants of the variant with the use of Phosphatovite - 2.45 pcs.

Under unfavorable weather conditions, not all beans are productive in legumes. Fertilizing with bacterial fertilizers contributes to an increase in the proportion of productive beans on the plant. Thus, the maximum share of productive beans was observed in the variant with Azotovite fertilization and averaged 93.0-95.5% in soybean and 74-76% in lentil in all years of research. In other variants of the experiment, there were differences by year. Nevertheless, on average for two years and in some years of research the proportion of filled beans in the control was lower than all variants with top dressing, on average it was 90.0% for soybean and 68.5% for lentil. In the conditions of 2020, the largest share of productive beans was obtained in the variant of the joint use of Azotovite and Phosphatovite.

The formation of the yield of legumes is influenced by the crop structure elements. Tables 1 and 2 show the results of the effect of bacterial fertilizers on the productivity elements of soybean and lentil plants.

In experiments with soy, fertilizing with bacterial fertilizer Azotovite contributed to an increase in the number and weight of seeds obtained from each plant compared to the control variant by 15.5 and 12.5%, respectively. Nevertheless, the size of the seeds remained at the control level – 156.0 g weight of 1000 pieces. At the same time, in this variant, the plants turned out to be the tallest. Fertilizing with bacterial fertilizer Phosphatovite increased all indicators of soybean productivity compared to the control. The maximum number of productive beans was formed on each plant in the experiment – 27.5 pcs., which exceeded the control by 44.7%, 55.5 pcs. of seeds were obtained on one plant, which is more than in the control by 59.0%, and their mass from the plant was higher than the control variant by 3.2 g or 57.1%. The seeds obtained in this variant also turned out to be larger and more filled in general, the weight of 1000 pieces was 160.2 g. With joint fertilizing with bacterial fertilizers Azotovite and Phosphatovite, the productivity indicators of soybean plants were at the level of the option with Phosphatovite fertilizing only, while exceeding the control and the option with fertilizing with Azotovite, but the size of the seeds was at the control level. In 2020, the indicators of the crop structure were higher than in 2019.

Table 1. The effect of bacterial top dressings on soybean productivity elements (average for 2019-2020)

Biometric indicators of plants	Experiment options			
	control	fertilizing with Azotovite	fertilizing with Phosphatovite	fertilizing with Azotovite+Phosphatovite
Number of productive beans per plant, pcs.	19.0	20.5	27.5	27.3
Average number of seeds per bean, pcs.	1.8	1.9	2.0	2.0
Number of seeds per plant, pcs.	34.9	40.3	55.5	53.0
Weight of seeds per plant, g	5.6	6.3	8.8	8.2
Weight of 1000 seeds, g	156.9	156.0	160.2	156.6

The use of top dressing with bacterial fertilizers on lentil crops has shown that they contribute to an increase in plant productivity. Thus, fertilizing with Azotovite on average over two years contributed to an increase in productive beans on the plant to 18.5 pcs., the number of seeds to 24.9 pcs. and their weight up to 1.4 g, which exceeded the control by 5.1, 16.4, and 16.7%, respectively. Also in this option, the most filled seeds were obtained, the weight of 1000 pieces was 59.0 g, which is 6.3% higher than the control. The maximum value in the experiment by the number of beans and seeds formed on each plant was obtained by fertilizing with Phosphatovite and its joint use with Azotovite. Thus, from each plant of these options, on average, 21.1-22.0 pieces of beans and 27.3 pieces of seeds were obtained, which exceeded the control and the option with the use of Azotovite. Despite the fact that the weight of 1000 seeds was slightly lower than in the variant with Azotovite fertilization, 1.6 g of seeds were collected from each plant in these options, which exceeded the control by 33.3% and the variant with Azotovite by 12.5%. 2019 turned out to be more favorable for lentil, when more productive beans were formed on plants and the seeds were larger than in 2019.

Table 2. The effect of bacterial top dressings on lentil productivity elements (average for 2019-2020)

Biometric indicators of plants	Experiment options			
	control	fertilizing with Azotovite	fertilizing with Phosphatovite	fertilizing Azotovite+ Phosphatovite
Number of productive beans per plant, pcs.	17.6	18.5	21.1	22.0
Average number of seeds per bean, pcs.	1.2	1.4	1.3	1.3
Number of seeds per plant, pcs.	21.4	24.9	27.3	27.3
Weight of seeds per plant, g	1.2	1.4	1.6	1.6
Weight of 1000 seeds, g	55.5	59.0	58.1	58.4

Bacterial fertilizers had an impact on the number and mass of nodules. In the options with the use of fertilizers, the number of nodules on soybean roots increased in the variant with Azotovite fertilization by 41.0% on average over two years, Phosphatovite - by 22.8%, with their combined use by 46.9%. More of them were observed in 2020. The weight of nodules from the plant was also maximal in the option with joint fertilization with Azotovite and Phosphatovite, where the excess of the control variant was 84.5%.

The microbiological activity of the soil when applying top dressing with bacterial fertilizers increases. Its highest indicator was obtained in variants with joint fertilization with Azotovite and Phosphatovite: in the experiment with soybean, it was 79.3% in 2019, 82.6% - in 2020, 86.2% - in the experiment with lentil in 2019 and 88.9% - in 2020. In other variants of the experiment, the microbiological activity of the soil was higher in the variant with the use of Azotovite.

In experiments with lentil, the positive effect of bioorganic fertilizers on the formation of nodules was also noted. On average, over two years, when fertilizing with Azotovite, the number of nodules on the plant increased by 132.0% compared to the control, and their weight by 98.0%. Fertilizing with Phosphatovite also contributed to an increase in nodules by 115.4%, in weight - by 74.8%. Joint fertilizing with these fertilizers had the maximum effect: the number of nodules increased by 144.1%, and the weight- by 106.2%.

The applied bacterial fertilizers contributed to an increase in the yield of legumes. Since the years of research differed in weather conditions, the yield was noticeably different by year (Table 3). In experiments with soybean, 2020 turned out to be more favorable, when an increase in yield was observed in all variants of the experiment compared to 2019. In 2019, the maximum yield increase was obtained in the variant with Phosphatovite fertilization of 3.22 t/ha, which exceeded the control by 36.4%. Fertilizing only with Azotovite did not have a significant effect on soybean yield. In 2020, all experimental variants significantly exceeded the yield control. The maximum yield increase was obtained in the variants where Phosphatovite was used: 31.2% in the variant of single-component top dressing and 19.7% in the variant of joint application with Azotovite.

The weather conditions of 2019 turned out to be more favorable for growing lentils. The yield this year was higher by an average of 0.48-0.74 t/ha. Phosphatovite showed the greatest efficiency in this year, in this variant the yield increased by 0.56 t/ha or by 30.1% compared to the control. All variants with the use of bacterial fertilizers significantly exceeded the control, but the differences between the variants where Azotovite was used as a top dressing turned out to be unreliable. In 2020, the maximum yield in the experiment was obtained in the variant with joint top dressing with bacterial fertilizers – 1.81 t/ha. All variants with top dressing significantly exceeded the control: with Azotovite by 25.4%, with Phosphatovite by 39.3%, their combined use by 48.4%.

Table 3. The effect of fertilizing them with bacterial fertilizers on the yield of leguminous crops

Options	Yield, t/ha			
	2019	2020	average for two years	deviation from control (+/-)
soybean				
Control	2.36	3.20	2.78	-
fertilizing with Azotovite	2.34	3.36	2.85	0.07
fertilizing with Phosphatovite	3.22	4.20	3.71	0.93
fertilizing with Azotovite+Phosphatovite	2.95	3.83	3.39	0.61
LSD_{05}	0.16	0.13		
lentil				
Control	1.86	1.22	1.54	-
fertilizing with Azotovite	2.27	1.53	1.90	0.36
fertilizing with Phosphatovite	2.42	1.70	2.06	0.52
fertilizing with Azotovite+Phosphatovite	2.29	1.81	2.05	0.51
LSD_{05}	0.14	0.19		

On average, Phosphatovite turned out to be the most effective of the studied bacterial fertilizers in the conditions of the republic for two years. The yield of soybean grain in the variant with Phosphatovite fertilization was 3.71 t/ha, which is 0.93 t/ha higher than the control, when combined with Azotovite, 3.39 t/ha of grain was obtained, the excess of the control was 0.61 t/ha. In experiments with lentil, on average for two years, the grain yield in variants with fertilizing Phosphatovite and together with Azotovite turned out to be almost the same - 2.06 t/ha, exceeding the control was 24.9%.

Top dressing with bacterial fertilizers contributed to an increase in the content of crude protein and crude fat in the grain of legumes. The content of crude protein in soybean grain increased by 0.44-0.58%, and fat by 0.15-0.3%, while there were practically no differences between the fertilizer options. The analysis of lentil grain showed that the greater accumulation of crude protein was promoted by fertilizing with Azotovite both as one-component (25.81%) and together with Phosphatovite (26.54%). Phosphatovite had a greater effect on the accumulation of crude fat. In both crops, bacterial fertilizers contributed to an increase in the nitrogen content in the grain (Table 4).

Table 4. Qualitative characteristics of the grain of leguminous crops when feeding them with micronutrients

Options	Content, %				
	crude protein	crude fat	fiber	nitrogen	crude ash
soybean					
Control	39.81	14.98	6.20	6.37	5.56
fertilizing with Azotovite	40.25	15.23	8.96	6.44	5.50
fertilizing with Phosphatovite	40.25	15.13	7.85	6.44	5.38
fertilizing Azotovite+ Phosphatovite	40.39	15.28	8.74	6.46	5.43
lentil					
Control	24.94	0.96	5.56	4.16	3.30
fertilizing with Azotovite	25.81	1.04	6.88	5.08	3.50
fertilizing with Phosphatovite	25.38	1.12	7.96	4.32	3.22
fertilizing Azotovite+ Phosphatovite	26.54	1.16	7.88	4.86	3.19

4 Conclusion

The conducted studies indicate the positive effect of bacterial fertilizers on the growth, development of soybean and lentil plants, as well as the formation of their yield. Thus, the use of Phosphatovite as a single component and in a mixture with Azotovite accelerated the maturation of legumes, which is of practical importance, since it allows to start harvesting soybean and lentil at an earlier date, which is important for the conditions of the Chuvash Republic.

Bacterial fertilizers used as root fertilizing contribute to an increase in the symbiotic activity of legume plants.

In experiments with soy, it was found that fertilizing with Azotovite allows to get more complete seeds. At the same time, fertilizing with Phosphatovite provides the greatest increase in soybean yield. Also, the positive effect of fertilizing on the formation of the lentil crop is obvious, which was primarily manifested in an increase in the number of productive beans and their share on plants, the formation of more fulfilled seeds on the plant.

The effect of bacterial fertilizers on the qualitative composition of legume grains was noted, top dressing increased the content of crude protein, crude fat, and nitrogen in the grain.

Despite the effectiveness of bacterial fertilizers on average over the years of research, it should be noted that the effectiveness of Azotovite depends on the availability of sufficient moisture in the soil, whereas the positive effect of Phosphatovite was observed in both years of research.

Thus, in the conditions of the Chuvash Republic, the most effective is the use of Phosphatovite as a root dressing and its joint application with Azotovite.

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